Griffing

On the Conditions of
Fatigue in Reading

REPRINTED FROM

Vol. III. No. 5. September, 1896.

THE

Psychological Review

EDITED BY

J. McKEEN CATTELL
COLUMBIA UNIVERSITY

AND

J. MARK BALDWIN
PRINCETON UNIVERSITY

CONTENTS.

PUBLISHED BI-MONTHLY BY

THE MACMILLAN COMPANY,

66 FIFTH AVENUE, NEW YORK; AND LONDON.

ON THE CONDITIONS OF FATIGUE IN READING.[1]

BY HAROLD GRIFFING AND SHEPHERD IVORY FRANZ.

The increasing part played by reading in the life of civilized man is a striking characteristic of modern culture. In fact, the man of to-day might be defined as a reading animal. The result of this strain upon the eye has been the wide prevalence of myopia, astigmatism and kindred disorders. But the functions which the optic mechanism is called upon to perform are not abnormal; the work of the eye differs only in degree from that for which it is fitted. If the eye were never fatigued, myopia would be rare.

Yet great as is their importance, we have little exact knowledge of the conditions of minimum visual fatigue. Cohn[2], Javal[3] and Weber[4] have treated the subject with great fulness, but their work was largely theoretical. Cattell[5] and Sanford[6] have, however, investigated the subject experimentally, with special reference to the relative legibility of letters.

The conditions of visual fatigue are obviously highly complex. They may be divided into two classes. On the one hand, we have all those conditions which pertain to the individual reader; for example, the time of reading, the position of head and eyes, and personal peculiarities, anatomical and physiological. Opposed to these are certain purely physical conditions. Such are the size and quality of the type, the intensity and quality of the illumination, the color and quality of the paper,

[1] From the Psychological Laboratory of Columbia University. Read in condensed form before the International Congress of Psychology, Munich, August, 1896.

[2] Cohn, *The Hygiene of the Eye in Schools*, Eng. tr., London, 1886.

[3] Javal, *Annales d'Oculiste*, 79–82; *Revue Scientifique*, 1881.

[4] Weber, *Ueber die Augenuntersuchungen in den höheren Schulen zu Darmstadt, Referat erstattet d. grossherz. Ministerial, März*, 1881.

[5] Cattell, *Philosophische Studien*, III.

[6] Sanford, *American Journal of Psychology*, I.

the clearness of the printing, the length of the lines, and the spacing between the letters and lines. It is this latter group of conditions with which we are now concerned.

(1) The Size of the Type.

Weber investigated the relation of the size of type to legibility by finding the maximum rate of reading. He arrived at the paradoxical result that although the rate of reading decreased for very small type it also decreased when the height of letters was over 2 mm[1]. By determining the time of exposure required for perception Cattell[1] studied the legibility of small Latin letters of different sizes, .7, 1.1, 1.8, 2.5 and 5.8 mm. The times found were 3, 1.4, 1.1, .7 and .6 for one observer, and 4, 1.7, 1.3, .9 and .7 for the other. The relation is approximately expressed by an hyperbolic curve.

The investigations of Cattell we have extended and supplemented by different methods. By the first method, which we will call the method of rapid reading, we found the rates at which an observer could read printed matter in large and small type. Two passages of the Bible, each containing 622 words, were used. One observer read one passage A, in large type, and another passage B, in small type, and the next observer read the same passages, reversing the order of the type, reading A in small type and B in large type. The order in which the experiments were made was also reversed for alternate observers. The time was taken by the observer with a stop watch, but recorded without his knowing the result by one of the writers. The observers were mostly students, five being familiar with experimental psychology. The type was Roman, *i. e.*, the ordinary type used in English books. The large type, of which we here give examples, was Pica, 1.8 mm. in height, the small, Pearl, .9 mm. in height. In addition to these experiments we made some in which the time of reading was constant, 1 minute, the number of words read being determined.

Below will be found the ratios of the times and of the number of words read.

[1] *Op. cit.*

[2] Not given by the writer, but calculated by us from other data given.

TABLE I.—RELATIVE TIMES FOR LARGE AND SMALL TYPE.

OBSERVER.	K	A	D_1	B	S	F_1	F_2	F_3	G	H_1	H_2	D_2	Av.
$\frac{T_L}{T_S}$	.77	1.04	.82	.61	.90	.88	.72	—	1.08	.96	1.01	.92	.90
$\frac{W_S}{W_L}$	.88	1.00	—	—	.91	.42	.65	.94	.80	—	—	—	

$\frac{T_L}{T_S}$ = ratio of time required to read large type to that required to read small type.

$\frac{W_S}{W_L}$ = ratio of number of words read in one minute in small type to the number read in large type.

In a few additional experiments the observers read at their natural rates. The resulting ratios $\frac{T_L}{T_S}$ for 4 observers were .87, 1.00, .86 and .81, the average .89, being the same practically as that obtained by the other method.

Thus it takes on the average about $\frac{9}{10}$ as much time to read large type, 1.8 mm., as to read small type, .9 mm. The difference in legibility would probably be much greater were it not that when the small type is read more words can be seen simultaneously. In this way we may explain Weber's paradoxical result. As the size of the letters increases beyond a certain limit the rate of reading will necessarily decrease; but this does not involve an increase of fatigue, as Weber assumed.

By a second method we found the relative number of words seen when exposed for $\frac{1}{20}$ sec. by Cattell's gravity chronometer.[1] Phrases of three and four words were pasted on white strips of cardboard and were shown for the time desired by a falling screen. The greater part of the screen was hidden from the view of the observer by a black sheet of paper with an opening where the letters were to appear. The phrases were cut from the books mentioned, the letters being 1.8 and .9 mm. high. None of the words were of more that two syllables. The same phrases were used for large and small type. There were 54 phrases of 3 words and 54 of 4 words, half in large type and half in small. Thus there were 216 + 162 words in all.

[1] For description of the instrument see *op. cit.*

The experiment was conducted as follows: The observer took his seat in a comfortable chair opposite the instrument and placed his chin upon a rest suitably adjusted, so that his eyes were slightly above the level of the letters exposed, and 30 cm. distant from them. The experimenter (one of the writers) stood behind the instrument so as to adjust the cards with the phrases. When the card was placed the observer fixated a gray cross on the black background of the movable screen directly in front of the letters, and let the screen fall by breaking the current with a Morse key. He then wrote down what he thought he had seen. A dozen or more practice trials were made before beginning the experiments proper. The observer was, of course, ignorant of the phrases that were to be given. Care was taken not to have a phrase already given in one type repeated immediately in another. Of eleven observers six completed only half of the series. We give below the results for the different observers.

TABLE II.—PERCENTAGES OF WORDS SEEN; LARGE AND SMALL TYPE.

	THREE-WORD PHRASES.			FOUR-WORD PHRASES.		
OBSERVER.	S.	L.	$\frac{S}{L}=\lambda$.	S.	L.	$\frac{S}{L}=\lambda$.
H.	.22	.56	.39	.13	.44	.29
C.	.46	.75	.61	.59	.75	.79
T. G.	.29	.75	.39	.23	.60	.38
I. F.	.60	.95	.63	.80	.88	.88
H. G.	.46	.81	.56	.66	.96	.69
P.	.46	.91	.50	.45	.85	.53
L.	.10	.54	.18	.18	.32	.56
R. G.	.76	.79	.96	.48	.68	.70
S.	.12	.47	.25	.12	.39	.31
A.	.68	.78	.87	.55	.69	.79
S. F.	.43	.85	.51	.59	.81	.73
Average			.53			.60

Vertical columns S and L give percentages of words seen for small and large type (.9 and 1.8 mm. high).

Vertical column $\frac{S}{L}$ give ratios in per cent. or the relative legibility λ of small and large type.

With the observers whose initials are given in block type the full set of experiments (108) were made, only 39 being made on the others.

In taking the average the values of λ for these five might be weighted. This would change the averages somewhat.

From the above table we see that on the average but little more than one half as many words were seen in small type as in large type. Individual variations are great, but these variations are probably not due to an appreciable extent to individual differences in the relative legibility of large and small type. For good observers the same difference in legibility would give different values of λ.

This theoretical conclusion is verified by the experiments. By arranging the observers in two groups according to the percentages seen, the values of λ is for the better observers in all cases lower than that of any of the four poorest observers.

A few experiments were made with 21 two-word phrases printed in very large type (4+ mm). The percentages of words seen correctly by three observers, together with the averages of the same observers for 1.8 mm. type as found from the table above given are as follows:

	Large	Very large
P.	.88	.93
L.	.43	.64
S.	.43	.70

Thus the legibility as shown by this method appears to increase regularly with the size. But since the number of words brought within the field of distinct vision decrease with the size, the relation is quite complex.

A few phrases (15) of two words each were used with the others. The percentages for two, three and four-word combinations were found to vary but little with the number of words.

From the table it will be seen that the values of λ were about the same for phrases of three words as for those of four words, the averages for phrases of 2, 3 and 4 words in small type being .42, .41 and .43.

In the above experiments the paper was not exactly the same for large and small type, being slightly grayish for the small type and of a more yellowish tint for the large. To eliminate this source of error, phrases of four words in large and small type were printed on the same white paper. From 200 experiments (800 words), 100 on S. F. and 100 on H., we found the following percentages of words seen:

	S	L	$\frac{S}{L}=\lambda$
H.	.12	.32	.37
S. F.	.83	.90	.92

The values of λ correspond quite closely with those previously found for the same observers, .88 for F. and .29 for H.

A modification of the preceding method was used by determining the time words composed of letters of different sizes had to be exposed in order to be seen. This we will call the time of exposure method. The same apparatus was used as before, the time of exposure varying with the extent of opening of the screen. This time can be determined to about $.15\sigma$, σ being .001 sec. The words were of not less than 5 letters, nor over 2 syllables, on white paper. The type, as here shown, was six point and 'eleven point,' .8 and 1.6 mm. high. On account of the preliminary practice necessary there were but three observers, two being the writers. The experiments were conducted in the same general way as those just described. The experimenter tried first very small times, increasing the time until the stimulus was perceived approximately 50% of the time. Then other words were shown which the observer had not seen. As the percentage seen tends to increase very rapidly from 0 to 100 (theoretically 99+), it was generally easy to determine at one sitting the time required either directly or by estimation from the percentage seen. The times of exposure found thus are now given in thousandths of a second.

Table III.—Times of Exposure for Different Sizes of Type to be Seen.

Observer.	L.	S.	$\frac{L}{S}=\lambda$
G.	1.6	1.9	.84
F	1.1	1.5	.73
"	1.3	1.7	.76
H	2.0	2.8	.71
"	1.6	2.5	.64
AV.			.73

L and S denote the times of exposure necessary for large and small type respectively, .8 and 1.6 mm.

$\frac{L}{S}$ or λ is the relative legibilty measured by this method.

The two values of L and S for F and H are for different days. The time of exposure seems to vary in the same individual.

From the above results it appears that the large type, 1.6 mm., requires about ¾ as great a time of exposure as the small type of half the height, .8 mm.

In the last two sets of experiments a few observations were made, which though not bearing on the special problems under investigation are yet of psychological interest. Observers generally failed to see any of the letters making up a word when they failed to perceive the whole word. There were, however, individual differences, some persons often seeing one or two letters only. At times an observer saw combinations without sense, though he knew such combinations were not given. In the time-of-exposure experiments the observer was at times conscious of perceiving letters without knowing what they were. Occasionally the observer had an impression that a given word was present, when the letters had not appeared distinctly. More often some letters were distinct, and he guessed the word, or else the whole word was distinct. One of the writers had a marked tendency to see again what had been given before, even when he knew that the word was not repeated. One of the observers, H., seemed to be an exception to the rule that one sees all letters exposed or none at all except within very small range of time. Some days it was very difficult to find the time required for this reason. But perhaps the most important phenomenon observed was the illusory perception of a word, the letters appearing distinct when not present. This has been already noted by Cattell and also by Münsterberg. The theoretical importance of this lies in the support which it gives to the hallucination theory of perception. The representative processes in perception seem to attain to the sensory vividness of true hallucinations. This does not, however, appear to take place in every instance, for F. seemed at times to see some of the letters and to infer by ordinary processes of association that a certain word was present.

To obtain more extended results and confirm those obtained by Cattell, by the time-of-exposure method, we determined the intensity of illumination necessary for the reading of letters of different sizes. The letters were printed in the simplest kind of type, commonly called Block. Two cards were, how-

ever, covered with words in Roman type, .8 and 1.6 mm. in height.

The observer sat in front of a stand from a projecting piece of which was suspended a small pendulum making a vibration in ½ sec. The pendulum swung in front of a screen having an opening where the letters to be seen appeared. The letters were, of course, shown ½ sec. The letters were posted on cardboard strips and these were placed in slits. The paper was the same for the different sizes, pure white. The slits were arranged so that the length of the cardboard exposed was either 15 or 3 mm., according to the size of the letters. For the two largest sizes, and also for the cards on which the words in Roman type were shown, the large area was used. The object was to show only one or two letters at a time, except when the Roman type was used, when a larger number was seen. A black screen in front of the pendulum with the necessary opening served to prevent distraction of the observer by the movement of the pendulum.

The observer's eyes were kept at a constant distance (30 cm.) from the stimulus by means of a chin rest. The light was that of a hooded petroleum lamp found to be fairly constant, shining through a square of ground glass 5 x 5 mm. The light emitted was approximately .02 candle power. The lamp was in a movable box sliding on wheels in iron grooves. Precautions were taken to avoid errors from reflected or diffused light. The letters used were in combinations of one to four words in one horizontal line. They were taken from a printer's sample book. The median plane of the observer was approximately perpendicular to the plane of the cardboard to be seen, and the lamp could be moved only in a straight line, making an angle of 45° with the plane of the cardboard.

With this apparatus after the observer had remained in the dark room long enough to avoid errors from adaptation (20 to 30 min.), the experiment was made as follows: A card with letters to be exposed was placed in the slit by the experimenter (one of the writers). The observer pushed back the pendulum to a fixed support with his hand, fixated a pencil cross on the cardboard piece fastened to the pendulum directly in front of

the letters to be seen, and then let the pendulum swing forward, observing the letters as they were shown. As the pendulum swung back it was caught by the observer with the left hand and fixed with a catch. He then moved the lamp nearer with the right hand. At first this was done by the experimenter, but with less convenience and economy of time. This was repeated until the observer was quite certain he could perceive the letters correctly when exposed but once. The distance of the light from the letters was then read off on a scale. The square of the reciprocal of this distance represents the relative intensity of the illumination. The readings were, of course, taken by the experimenter. For this purpose we used the light from a small candle inside a blackened box shining through a cylindrical tube. Two or three determinations were generally made at one sitting for each of the variables under investigation, including several in addition to the type. Variations in the results made it necessary to average the records of some days separately, as given in the second horizontal columns for F and H.

We give below the average values of T, the illumination threshold[1] for reading in terms of one candle-meter (C.M.), or the light of a standard candle at a perpendicular distance of one meter.

TABLE IV.—ILLUMINATION THRESHOLDS FOR DIFFERENT SIZES OF TYPE.

OBSERVER.	N	H = .9		H = 1.6		H = 3.1		H = 6.0		h = .		h = 1.6	
		Av	MV	Av	MV	Av	MV	Av	MV	Av	MV	Av	MV
G	10	27	.02	.12	.01	.042	.003	.014	.001	.36	.04	.14	.01
F	6	.24	.02	.08	.01	.028	.007	.010	.001	.22	.02	.12	.02
"	3	.17	.03	.045	.004	.018	.002	.008	.001	.13	.01	.05	.00
H	5	.077	.014	.035	.007	.014	.001	.003	.000	.19	.01	.07	.00
"	3	.19	.02	.09	.003	.043	.003	.009	.001	.35	.03	.13	.02

H=height of Gothic letters in mm.

h=height of Roman letters in mm.

N=number of determinations upon which average is based.

Av=average.

MV=mean variation.

[1] Calculated by the formula $T=\frac{\lambda \cos\theta}{d^2}$ where λ is the candle power of the light, d the distance of the light from the object, and θ the angle made by the normal to the surface.

A graphical representation of the results is shown in the accompanying figure. The ordinates give the intensity of illumination in candle-meters, and the abscissas the height of the letters in tenths of millimeters.

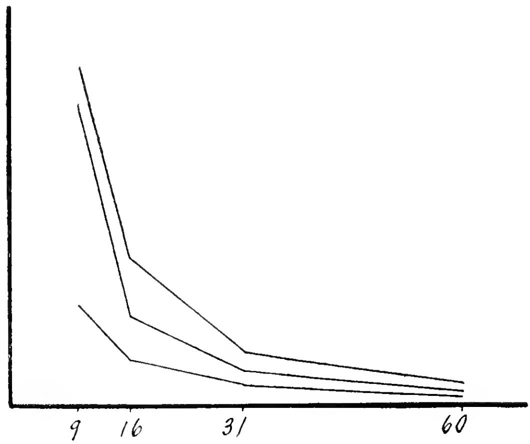

FIG. 1.

The curves resemble rectangular hyperbolas, the values of the variables corresponding roughly to the equation,

$$(s-k)\ i = k_1,$$

k and k_1, being constants depending upon the individual. Assuming such an equation we may infer that after the size of the type has reached a certain limit the increase of size is in direct proportion to the decrease of illumination. The fatigue coefficient increases slowly until the size of the type decreases to about 2–3 mm., after which its increase is more and more rapid. The lowest limit to the size of type in common use should be 1.5 mm. The same conclusion may be drawn from the experiments of Cattell already mentioned.

(2) THE QUALITY OF THE TYPE.

On theoretical grounds it may be assumed that the legibility of letters decreases with increasing complexity of structure. From this point of view German type is open to serious criti-

cism, and even our Roman type might evidently be much improved. Some of our letters have unnecessary features and they are as a rule much more complex in structure than those printed in the so-called Block type. Many letters, such as c and e, are easily confused, and there are decided differences of legibility. These differences are, indeed, slight and difficult to determine. By finding the percentage of times each letter was seen when exposed for 1σ, more or less, Cattell[1] found the order of legibility of the small letters to be: d k m q h b p w u l j t v z r o f n a x y e i g c s. There seemed to be, however, individual differences. Sanford[1] by a different method found a somewhat different order of legibility.

In the writers' experiments, which were made only by the most delicate method, that of the illumination threshold, the following styles of type were used: Roman (small letters), that used universally in England, America and southern Europe for books and newspapers; German, or that used in Germany; Block, in which the letters are of uniform thickness and of the simplest shape, much like Roman capitals. Two styles of Block were used, as here shown; in one the letters being quite **THICK**, .5 mm., whereas in the OTHER they were .15 mm. Besides the ordinary Roman letters there were two other sets in semi-Roman type; one, **Roman II.**, having very thick and very thin lines, .05 to .5 mm.; the other, Roman III., being somewhat like the plainer Block and of uniform thickness, about .2 mm. The size of the letters was practically constant for the different groups, 1.5 mm. in height, there being, however, slight variations, to .1 mm. in the individual letters.

We give now the results in tabular form. The figures mean the same as in Table IV. The results for F. and H. are given in 2 columns on account of a variation in sensibility which made it necessary to average the results of the earlier experiments separately.

[1] *Op. cit.*

TABLE V.—ILLUMINATION THRESHOLD FOR DIFFERENT KINDS OF TYPE.

		Roman I.		Roman II.		Roman III.		German		Block thin.		Block thick.	
Observer.	N	AV	M V	AV	M V	AV	M V	AV	M V	AV	M V	AV	M V
G.	10	.22	.02	.12	.02	.18	.02	.21	.03	.20	.02	.09	.01
F.	6	.14	.01	.12	.02	.13	.01	.15	.02	.13	.01	.07	.01
"	3	.11	.01	.06	.001	.08	.00	.12	.01	.10	.00	.06	.00
H.	5	.10	.01	.06	.01	.12	.02	.12	.02	.10	.02	.04	.00
"	3	.22	.03	.15	.03	.22	.02	.24	.02	.22	.01	.10	.00

From the above table we may calculate the relative legibility λ of the different styles of type; λ of course being the reciprocal of the illumination threshhold given above.

The values of λ are now given.

TABLE VI.—RELATIVE LEGIBILITY OF TYPE, THAT OF ROMAN BEING I.

Observer.	Roman II.	Roman III.	German.	Block thin.	Block thick.
G.	1.8	1.2	1.0	1.1	2.4
F.	1.1	1.1	.9	1.1	2.0
"	1.8	1.4	.9	1.1	1.8
H.	1.7	.8	.8	1.0	2.5
"	1.5	1.0	.9	1.0	2.2
Av	1.6	1.1	.9	1.1	2.2

From the above we see that, contrary to our expectation, the difference in legibility between Roman and German type is relatively slight. Thin hair lines, if accompanied by thick lines, do not seem to diminish the legibility, Roman II. requiring nearly half as much light as Roman I. The complexity of the letters, within the limits here studied, does not seem to have decided effect on the legibility, for the value of λ for thin Block is about the same as for Roman. The greater legibility of Block type is due almost entirely to the thickness of the letters, as shown by these experiments. On the other hand, if a part of the letter is thick it is quite legible, even though thin hair lines are frequent. It is, however, probable that type such as Roman II. is

more fatiguing than the results indicate. It may be possible for the mind to perceive certain objects with fatigue when other objects are either perceived without appreciable fatigue, or not perceived at all.

(3) The Distance Between the Letters and Lines.

The horizontal distance between the letters has been said by Javal to be of great importance. Certainly a word printed so that these distances is increased .8 to 1.3 mm. appears to be much more distinct. The effect of an increase in this spacing is here shown. But twelve experiments on three observers by the illumination threshold method gave negative results. We must conclude then that the spacing commonly used is quite sufficient. Greater spacing would, of course, be more expensive, and the decrease of fatigue not as great as might be brought about in other ways.

As regards the vertical space between the lines, technically called 'leading,' a slight effect on legibility was found when the distance with Pearl type, .8 mm. high, was increased from .8 to 1.3 mm. The illumination threshold method was used, and the experiments carried on simultaneously with the preceding. The following results were obtained:

Table VII.—Illumination Threshold for Type Leaded and not Leaded.

	.8 mm.		1.3 mm.		λ
	Av	MV	Av	MV	
G.	.40	.03	.36	.04	.90
F.	.25	.01	.22	.02	.88
"	.12	.01	.12	.00	1.00
H	.12	.01	.09	.01	.75
"	.35	.02	.27	.01	.77
Av					.86

Thus the average relative legibility of unleaded type to leaded type, as measured in this way, is about .9.

(4) The Intensity of Illumination.

Although the variation in the intensity of diffused daylight in a well lighted room is known to be very great, even when the other conditions such as time and place are constant, being roughly from 50 to 1500 candle-meters,[1] no results were obtained for variations in legibility due to this variation by the two gravity chronometer methods and the method of rapid reading. The problem is, however, difficult to investigate in this way by reason of the marked daily variations in individual sensibility. It was necessary, therefore, to use artificial light of low intensity. The relation of the intensity and the legibility under these conditions has already been studied by Cattell by the time of exposure method. Using the light of a petroleum lamp (about 10 candle power) 18 cm. distant at an angle of 55° as the unit of illumination, *i. e.*, about 260 c. m., the times of exposure for the intensities 1, $\frac{1}{4}$, $\frac{1}{16}$, $\frac{1}{64}$, $\frac{1}{256}$, were 1.4σ, 1.7, 2.5, 6. and 20.

In order to supplement the work of Cattell we determined the maximum rate of reading for different intensities of illumination. It had already been found by Weber[2] that for low intensities the rate of reading varies with the illumination. Our experiments were made in the following manner: The book to be read, the Pearl type Bible already mentioned, was fastened on a wooden stand so as to be in front of the observer, and making an angle of 45° with the rays of light. The light used was a standard candle placed inside a blackened box. The conditions were such that the light came from behind the observer and to his left. The observer read one column as fast as possible, recording the time with the stop watch. With the lowest intensity, however, on account of fatigue, but half a column was read, the time being doubled for the whole column, The observer, it should be added, remained in a dark room long enough to avoid errors from adaptation. The experiments were made on one day by each observer. Below are given the results in seconds for the different distances in meters and the relative intensities in candle-meters.

[1] Cohn, *op. cit.*
[2] Weber, *op. cit.*

TABLE VIII.—TIME OF READING AT DIFFERENT INTENSITIES.

OBSERVER.	DAY-LIGHT.	¼ M. 11.2 C. M.	½ M. 2.8 C. M.	1 M. .7 C. M.	1½ M. .35 C. M.	2 M. .17 C. M.
H G	35	36	36	46	63	110
K	45	44	39	53	83	120
F	47	51	52	69	100	170
G	47	49	59	72	130	—
S	29	29	35	48	—	—

In these experiments the rate of reading does not appear to be appreciably affected by a decrease of illumination within a very wide range, the intensity of good daylight being about 500 times as bright as the lowest intensity here used, with which the rate of reading was not appreciably increased. We conclude then that within wide limits such as those of ordinary daylight variation in the intensity of illumination is not attended by great fatigue. But when the illumination decreases to a certain point, not far from 3 C. M., the fatigue becomes excessive. This is shown by the fact that very slight differences in the rate of reading are caused by conditions of great fatigue, an increase of about $\frac{1}{9}$ in the time of reading corresponding to decrease in the illumination threshold of 70 per cent.

The above experiments correspond quite well with those of Cattell by the time-of-exposure method. His results show that the fatigue coefficient increases very rapidly as the illumination decreases below approximately 4 C. M. His experiments also show that the fatigue coefficient is appreciably greater for the lamp light, about 250 C. M., than for daylight, and that it increases as the illumination is further decreased.

(5) THE QUALITY OF THE ILLUMINATION.

The use of artificial light has long been recognized as an important cause of visual fatigue. This fatigue may be partly ascribed to the conditions of intensity, the light of a good petroleum lamp at convenient reading distance being less than that of good daylight. We, therefore, tested the effect of artificial light of high intensity by using the light from an incandescent Welsbach gas burner giving clear, white light, 35 candle power at 25 C. M. and 45°, about 400 C. M. The times of

exposure required for perception by the writers were found to be as given below.

	Small Type.		Large Type.	
	Welsbach.	Daylight.	Welsbach.	Daylight.
G	1.8	1.9	—	—
F	1.1	1.5 1.7	.8	1.1 1.3

These values are thus smaller, rather than larger, than those already found for daylight. We must suppose the decrease in time to be due to daily variations. The above measurements were made on one day, and the perceptive and retinal processes of F were more than usually delicate. The smallest time found $.8\sigma$, is about as small as any found by Cattell in all his experiments. It is evident, therefore, that with sufficient intensity of white artificial light the legibility of printed matter may be as great as in good daylight.

Gas light and lamplight have, in addition to their frequent unsteadiness, the disadvantage of a yellow color. Since, as will be seen later, yellow paper is unfavorable for reading, yellow light causing the paper to appear yellow must also be a source of fatigue.

(6) The Quality of the Paper.

If the paper used reflects very little light and is of such a quality that letters can be well printed, the exact hue is probably of little importance, provided a large quantity of light be diffused. But if the absorption be so great that the paper appears grayish, letters printed on it will not be so legible by reason of the lessening of the contrast between the letters and the background.

In experiments made by the different methods already described we used non-reflecting clear white paper and gray paper, technically called news-paper, the same as that used by many newspapers, only slightly darker. By the color-wheel method it was found that the white paper used had to have 30 per cent. black mixed with it to give a gray corresponding to this. Its relative luminosity was therefore about .70. Specimens of red and yellow paper were also used, the red corresponding to the spec-

trum color just to the left of Frauenhofer's line C, and the yellow that to the right of line D ($\frac{1}{5}$ of the distance to line E).

Experiments by the method of the percentage of words seen on one observer with 11-point type gave negative results, the percentages of words seen out of 150 being 32 per cent. and and 31 per cent., the same for white paper as for the newspaper. Of small type words, 6-point, given at the same time, the same observer, H., saw but 12 per cent.

By the time-of-exposure method, however, different results were obtained. Below are the times found for two observers.

	White.	News.	Yellow.	Red.
G.	2.8	4.0	4.0	—
F.	1.2	1.7	2.5	4.0

Thus the time of exposure is considerably longer for gray tinted paper, as well as red and yellow paper, than for white. The explanation of the greater legibility of the letters on white paper over those on the red and yellow is the same as for the gray. Color quality is not independent of intensity, white being essentially brighter than yellow, which in turn is brighter than red.

The illumination method was also applied to the study of the fatigue effect of white paper and gray newspaper. The letters were not read independently in these experiments, but in words. Upon the paper exposed were 10 to 12 words in 3 lines.

The values of the illumination threshold were as follows:

TABLE IX.—ILLUMINATION THRESHOLDS FOR WHITE AND GRAY PAPER.

OBSERVER.	G		F		F_1		H		H_1	
	Av	MV	Av	MV	Av	MV	Av	MV	Av	MV
W = White	.10	.01	.10	.01	.06	.01	.04	.00	.10	.02
N = News	.20	.02	.16	.02	.08	.01	.07	.00	.23	.01
$\frac{W}{N} = \lambda$	.50		.62		.75		.57		.43	

According to these results the gray tinted newspaper required about twice as much illumination as the white. This is

somewhat more than might be expected from the relative absorption powers of the papers, but the quality of the printing varies with the paper, not being quite so clear on the newspaper.

Summarizing briefly our results we conclude that the size of type is the all important condition of visual fatigue. No type less than 1.5 mm. in height, that in which this article is printed (eleven point), should ever be used, the fatigue increasing rapidly even before the size becomes as small as this. The intensity of illumination is apparently of little consequence within the limits of daylight in well lighted rooms. Very low intensities, less than from 3 to 10 candle-meters, are sources of even greater fatigue than small type, and 100 C. M. may be considered a safe limit. Yet the illumination in German school rooms has been found to be frequently less than 2 C. M. White light rather than yellow light should be used for artificial illumination. The form of the type is of less importance than the thickness of the letters. White paper should be used, though it is possible that the greater amount of light reflected from pure white paper may cause some fatigue. Additional 'leading' or spacing between the lines, is also desirable.